UDC 621.391.812.44

1969
THE QUEEN'S AWARD
TO INDUSTRY

RESEARCH DEPARTMENT REPORT

# Variation of medium-frequency sky-wave field strength with solar activity in Europe

No. 1971/11

Research Department, Engineering Division
THE BRITISH BROADCASTING CORPORATION

RESEARCH DEPARTMENT

# VARIATION OF MEDIUM-FREQUENCY SKY-WAVE FIELD STRENGTH WITH SOLAR ACTIVITY IN EUROPE

Research Department Report No. **1971/11**
UDC 621.391.812.44



It uses SI units in accordance with B.S. document PD 5686

Work covered by this report was undertaken by BBC Research Department for the BBC and the ITA

D. Maurice

Head of Research Department

J.O. Drewery, M.A., Ph.D.,
P. Knight, B.A., M.I.E.E.

(RA-75)

Research Department Report No. 1971/11

# VARIATION OF MEDIUM-FREQUENCY SKY-WAVE FIELD STRENGTH WITH SOLAR ACTIVITY IN EUROPE



(RA-75)

April 1971

Research Department Report No. 1971/11
UDC 621.391.812.44

# VARIATION OF MEDIUM-FREQUENCY SKY-WAVE FIELD STRENGTH WITH SOLAR ACTIVITY IN EUROPE

**Summary**

*Medium-frequency sky-wave field strengths measured late at night during the solar cycle have been analysed. The reduction in field strength due to solar activity has been found to depend significantly on the distance between transmitter and receiver. A modified field-strength correction based on sunspot number and distance is proposed.*

## 1. Introduction

The strength of medium-frequency sky waves propagated at night is known to depend to a small extent on solar activity. Enhanced solar activity increases the electron density in the lower part of the ionosphere and leads to increased absorption. Field strengths therefore tend to be lower when solar activity is high, i.e. when the sunspot number is large.

The relationship between field strength and sunspot number has been studied by the EBU,[1] who concluded that solar activity reduces field strengths in Europe by $0{\cdot}02R$ decibels, where $R$ is the sunspot number. This result, which was derived from measurements made on a number of paths at frequencies in the l.f. and m.f. bands, is independent both of frequency and distance. It has been provisionally adopted as a field-strength correction by the CCIR.[2]

On theoretical grounds the field-strength reduction would be expected to depend on the great circle distance between transmitter and receiver. If this distance is doubled, for example, the distance traversed by a wave in the ionosphere is also approximately doubled, except on the very shortest paths. Consequently both the total ionospheric absorption (in decibels) and the absorption increase due to solar activity would tend to be doubled. It is reasonable to assume, therefore, that the field-strength reduction due to the influence of the sun is roughly proportional to distance.

In order to confirm that the reduction in field strength due to solar activity varies significantly with distance, some of the EBU data have been re-analysed. These data consist of median field strengths measured during one-hour periods shortly before midnight. The measurements were made on a number of paths, on about 12 nights each month, between 1953 and 1958; details of the paths and measurement periods are contained in Reference 1. Measurements of Kishinev, USSR (998 kHz) made in Lisbon from 1958 to 1961 were also included.

## 2. Preliminary investigation

A preliminary comparison was made between field strengths measured in 1954 (sunspot minimum) and 1957 (sunspot maximum). The investigation was confined to measurements made in June and December only, because in these months sunset time is also constant. This ensured that diurnal variations, which depend mainly on the time which elapses after sunset, did not influence the comparisons.

The means and standard deviations of field strengths measured in the two years were determined and statistical tests were applied to see if they differed significantly. Six paths included data for June of both years but only three of these paths included data for December of both years. Only three of these nine pairs showed a significant difference between sunspot maximum and minimum because the large standard deviations outweighed the differences between the means. It was therefore decided to investigate the interdependence between solar activity and field strength by means of a regression analysis.

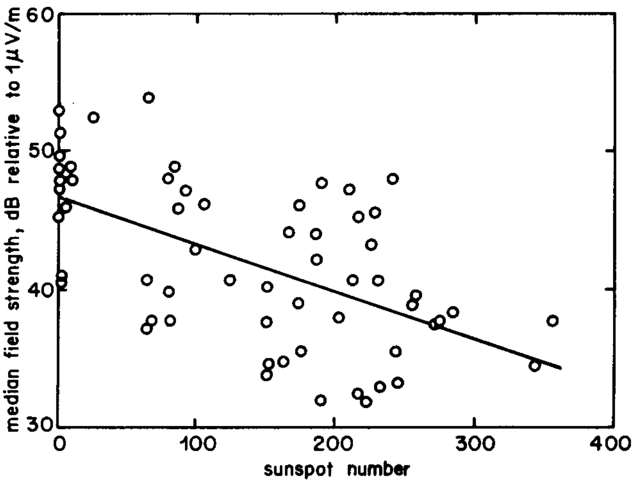


*Fig. 1 - Variation of field strength with solar activity on a typical path (Rome—Oslo, December)*

## 3. Variation of field strength with sunspot number

Fig. 1 shows an example of the manner in which the median field strength measured at a fixed hour after sunset varies with sunspot number on a typical path. The tendency of the field strength to decrease as the sunspot number increases will be noted.

Fig. 1 also shows a regression line, computed on the assumption that the relationship between field strength in decibels and sunspot number is linear. This assumption is justifiable because the attenuation in decibels of radio waves in the ionosphere is proportional to electron density. In the lower ionosphere the electron density during the day, and the residual electron density at night, is approximately proportional to $(1 + 0{\cdot}01R)^{1/2}$, which is a measure of total solar activity.[3] Fig. 2 shows that the relationship between $R$ and $(1 + 0{\cdot}01R)^{1/2}$ is almost linear within the range of observed sunspot numbers. Consequently an almost linear relationship between field strength in decibels and sunspot number is to be expected.

The regression analysis was based on the measurements made in all the months of June and December during the period 1953 to 1958. During this period the daily sunspot number varied from 0 to 355 and was treated as the independent variable. On some paths, measurements were not made for the whole period; they were excluded if the range of sunspot numbers was less than half the possible range, since they would not be expected to yield reliable estimates of regression coefficients. Separate analyses were made for June and December, the average number of measurements included in each analysis being about 45.

Each analysis gave an estimate of the regression coefficient $b$, which may be defined as the change in field strength for unit change of sunspot number. The results obtained on each path are listed in order of increasing path length in Table 1, and may be compared with the mean value of $-0{\cdot}02$ derived by the EBU. Also tabulated are the standard errors of $b$, which indicate the accuracies of the estimated values.*

On each path the values of $b$ estimated for June and December were compared. Significant differences (at the 5% level or less) were found on only three paths. It is reasonable to conclude, therefore, that no distinction need be made between the measurements made in June and December. In both months the measurement period was several hours later than sunset and nocturnal conditions were well established. It is possible that values of $b$ measured nearer to sunset might differ significantly from those contained in Table 1, because total ionospheric absorption would then be much greater.

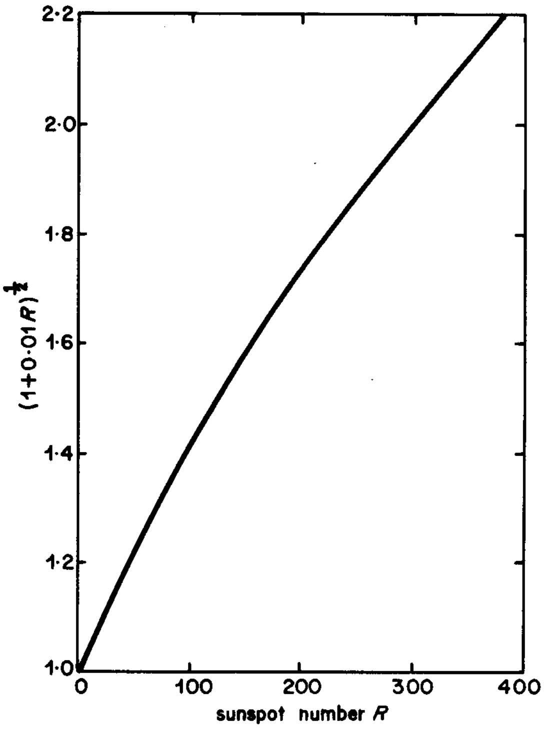


*Fig. 2 - The function $(1 + 0{\cdot}01\ R)^{1/2}$*

## 4. Variation of regression coefficient with distance

The regression coefficients contained in Table 1 are plotted as a function of distance in Fig. 3; a tendency for the magnitude of the regression coefficient to increase with distance can be seen.

Since the absorption increase due to solar activity was expected to be roughly proportional to distance, a linear regression analysis of $b$ with distance was undertaken. This regression was found to be highly significant** and the regression line is therefore shown in Fig. 3. This line is, of course, an estimate of the true regression line; the fact that it almost passes through the origin is fortuitous.

* There is a 95% probability that the true value of $b$ differs from the estimated value by less than twice the standard error.

** Statistical significance of regression is discussed in the Appendix Section 9.

*TABLE 1*

*Estimated Regression Coefficients*

| Path | Path length | Regression coefficients June (units of $10^{-2}$) | December | Standard errors of $b$ June (units of $10^{-2}$) | December |
|---|---|---|---|---|---|
| Monaco–Chatonnaye | 326 | 0·97 | –0·32 | 2·18 | 1·24 |
| Rome–Monza | 509 | –1·26 | –0·85 | 0·52 | 0·61 |
| Monaco–Limours | 681 | –2·74 | –0·54 | 1·13 | 0·63 |
| Rome–Belgrade | 728 | –3·09 | –1·48 | 0·73 | 0·57 |
| Monaco–Jurbise | 797 | – | –1·56 | – | 1·03 |
| Rome–Nuremburg | 876 | 0·76 | –1·08 | 0·59 | 0·65 |
| Horby–Tatsfield | 1034 | 2·02 | – | 2·18 | – |
| Monaco–Berlin | 1070 | 0·99 | –3·06 | 1·20 | 0·82 |
| Horby–Chatonnaye | 1123 | –2·45 | –3·77 | 0·91 | 1·06 |
| Rome–Limours | 1128 | –1·92 | 0·07 | 0·55 | 0·37 |
| Horby–Lulea | 1177 | –1·53 | –0·92 | 1·52 | 0·93 |
| Horby–Monza | 1178 | 0·55 | –1·00 | 0·71 | 0·75 |
| Horby–Belgrade | 1314 | –4·47 | –0·94 | 1·37 | 1·53 |
| Rome–Wittsmoor | 1343 | –1·58 | – | 1·51 | – |
| Monaco–Copenhagen | 1381 | –0·95 | –2·85 | 1·32 | 0·94 |
| Rome–Tatsfield | 1431 | –1·40 | –1·61 | 0·66 | 0·49 |
| Monaco–Lisbon | 1499 | 0·54 | 2·95 | 1·33 | 2·18 |
| Rome–Lisbon | 1878 | –1·44 | –1·69 | 0·65 | 0·57 |
| Rome–Oslo | 2008 | –5·21 | –3·43 | 1·11 | 0·64 |
| Kishinev–Lisbon | 3235 | –5·90 | –3·80 | 1·51 | 1·42 |
| Rome–Azores | 3274 | –0·91 | –2·71 | 1·50 | 0·88 |

Transmitter frequencies

| | | | |
|---|---|---|---|
| Rome | 845 kHz | Horby | 1178 kHz |
| Kishinev | 998 kHz | Monaco | 1466 kHz |

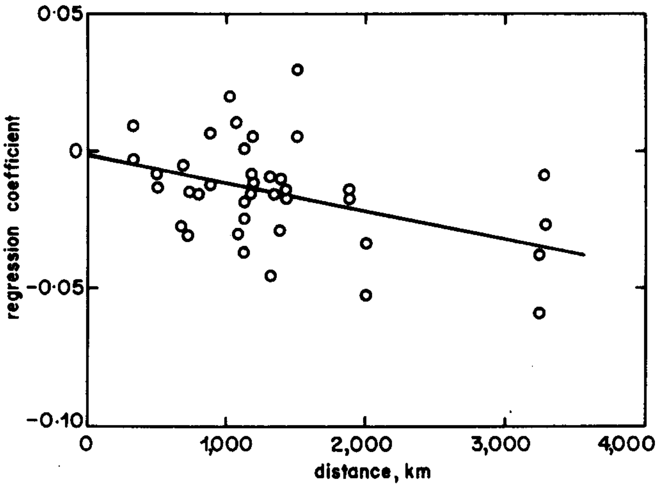


*Fig. 3 - Variation of regression coefficient with distance*

A very close approximation to the regression line of Fig. 3 is given by the equation

$$b = -D \times 10^{-5} \tag{1}$$

where $D$ is the distance in km. When $D$ = 2000 km the value of $b$ is identical with that derived by the EBU.

Most of the individual values of $b$ shown in Fig. 3 are compatible with Equation (1). Significance tests based on the standard errors contained in Table 1 showed that only 9 of the estimated values of $b$ differ significantly (at the 5% level or less) from values calculated from Equation (1).

Since the change of field strength $\Delta E$ due to solar activity is equal to $bR$ dB, the combined effect of sunspot number and distance is given by

$$\Delta E = -RD \times 10^{-5} \text{ dB} \tag{2}$$

Equation (2) is a modified correction for solar activity which may be used in field-strength prediction.

## 5. Variation of regression coefficient with frequency

The values of $b$ contained in Table 1 were multiplied by $1000/D$ to obtain equivalent values for a distance of 1000 km. They were then divided into three groups corresponding to the three principle transmitter frequencies* and an analysis of variance was performed. It was found that the variance within groups exceeded the variance between groups, and it was concluded that the measurements provided no evidence of a significant dependence of regression coefficient upon frequency within the m.f. broadcasting band.

## 6. Conclusions

A re-analysis of medium-frequency sky-wave measurements made during the night by the EBU supports the earlier conclusion that field strength decreases as solar activity increases. On theoretical grounds the field strength decrease would be expected to be roughly proportional to the distance between transmitter and receiver, and the re-analysis has shown that this is so. A modified field-strength correction based on distance as well as sunspot number is therefore proposed. Since the measurements were made late at night, this field-strength correction may not be valid within two hours of sunset or sunrise, when ionospheric absorption losses are much greater. No significant variation of the field-strength reduction with frequency could be detected within the m.f. broadcasting band.

Although the proposed field-strength correction was derived from measurements made in Europe, it should apply in all temperate latitudes and also to East-West paths in tropical latitudes. It may not be valid on North-South paths in tropical latitudes, however, because the total absorption on these paths is smaller.

* The measurements of Kishinev, 998 kHz, were excluded because they yielded only one value of $b$.

## 7. Acknowledgement

Thanks are due to the Technical Director of the EBU for providing a copy of the detailed results of the measuring campaign.

## 8. References

1. EBERT, W. 1962. Ionospheric propagation on long and medium waves. EBU Document Tech 3081, 1962.
2. Predictions of ionospheric field strength and propagation loss for the frequency range between 150 and 1500 kHz. CCIR Report 264–1, Documents of the XIth Plenary Assembly, Oslo, 1966, Vol. II, pp. 297 – 321.
3. ALLEN, C.W. 1948. Critical frequencies, sunspots and the sun's ultra-violet radiation. *Terr. Magn. atmos. Elect.*, 1948, **53**, pp. 433 – 438.

## 9. Appendix: the significance of a linear regression

Suppose pairs of values are plotted as points in the x-y plane and y is designated the dependent variable whose regression upon x is sought. The y values will possess a variance about a mean which will be composed of two factors. One factor can be attributed to the existence of a regression line and the other to a scatter about this regression line. A regression is highly significant if the variance due to the regression line is much greater than the variance about the regression line. A significance test (the F-test) is applied to the ratio between these two variances to determine whether the regression is significant. The slope of the regression line, termed the regression coefficient, is subject to error and, in general, a highly significant regression will possess a high ratio of regression coefficient to its standard error.

SMW/JUC

Printed by BBC Research Department, Kingswood Warren, Tadworth, Surrey